IB/2004/051262
PHDE030350EPP

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03103790.6 ✓

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Anmeldung Nr:
Application no.: 03103790.6
Demande no:

Anmeldetag:
Date of filing: 14.10.03
Date de dépôt:

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Iterative data reconstruction

In Anspruch genommene Priorität(en) / Priority(ies) claimed /Priorité(s) revendiquée(s)
Staat/Tag/Aktenzeichen/State/Date/File no./Pays/Date/Numéro de dépôt:

Internationale Patentklassifikation/International Patent Classification/
Classification internationale des brevets:

G06T11/00

Am Anmeldetag benannte Vertragstaaten/Contracting states designated at date of filing/Etats contractants désignées lors du dépôt:

AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LU MC NL
PT RO SE SI SK TR LI

DESCRIPTION

Iterative data reconstruction

The present invention relates to the field of iterative data reconstruction, e.g. in computed tomography. In particular, the present invention relates to a method of performing an iterative data reconstruction, to an image processing device and to a computer program for an image processing device.

Iterative methods can be used for data reconstruction in different fields of data processing, such as nuclear science and computed tomography. In particular, iterative algorithms are applied for image reconstruction. The reconstruction process consists of alternating projection and backprojection steps. In order to efficiently use dedicated image reconstruction hardware, multiple projections/backprojections have to be carried out simultaneously. In known methods, for example, as described in IP 0 502 187 B1 or US 6,574,299 B1, such image reconstruction still requires long processing times. In particular, the application of multiple projections/backprojections, which may be carried out simultaneously, may lead to a slow convergence, due to correlations between the simultaneously processed data and, consequently, to a low image quality.

It is an object of the present invention to provide for an improved iterative data reconstruction.

According to an exemplary embodiment of the present invention as set forth in claim 1, the above object may be solved by a method of performing an iterative data reconstruction, wherein projection data is determined from estimated data for a plurality of projections. Then, a difference between the estimated data and measured data is determined. Then, according to an aspect of the present invention, a filtering of the difference is performed, resulting in a filtered difference. Then, a backprojection is

performed by updating the estimated data by using the filtered difference. These steps may be performed iteratively.

Due to the filtering step, the difference is adapted or manipulated before performing the backprojection. This may allow for an improved processing speed, i.e. for a reduced processing time. Furthermore, in case the method is applied, for example, for the reconstruction of images, an improved image quality may be achieved.

According to another exemplary embodiment of the present invention as set forth in claim 2, the filtering is performed such that a mutual influence or reciprocal interaction of the plurality of projections is at least partially filtered out. In other words, according to this exemplary embodiment of the present invention, the difference is modified such that an influence on a projection caused by other projections is compensated for before backprojection.

Advantageously, due to the introduction of such a filtering step, the method according to this exemplary embodiment of the present invention may be implemented efficiently, for example, on dedicated image reconstruction hardware and may allow to perform several projections/backprojections simultaneously, allowing for a reduced processing time.

According to another exemplary embodiment of the present invention as set forth in claim 3, the method is based on the algebraic reconstruction technique (ART).

Claims 5 to 7 provide for further exemplary embodiments of the method according to the present invention.

According to another exemplary embodiment of the present invention as set forth in claim 8, an image processing device is provided, performing an iterative data reconstruction, for example, similar to the ART, including a filtering before a

backprojection, allowing for a reduced processing time, while still allowing for a high reconstruction quality.

The present invention also relates to a computer program, for example, for an image processing device, for performing an iterative data reconstruction, including a filtering step. The computer program according to the present invention is defined in claim 9. The computer program according to the present invention is preferably loaded into a working memory of a data processor. The data processor is thus equipped to carry out the method of the invention. The computer program may be stored on a computer readable medium, such as a CD-ROM. The computer program may also be presented over a network, such as the WorldWideWeb, and may be downloaded into the working memory of the data processor from such a network.

It may be seen as the gist of an exemplary embodiment of the present invention that a filtering step is introduced into an iterative data reconstruction, such as ART or simultaneous ART (SART). ART is, for example, described in R. Gordon *et al* "Algebraic reconstruction techniques (ART) for three-dimensional electron microscopy and x-ray photography" J. Theor Biol. Vol. 29, pages 471 to 481, 1970, which is hereby incorporated by reference. SART is, for example, described in R.H. Andersen *et al*, "Simultaneous algebraic reconstruction technique (SART)" Ultrasonic imaging, Vol. 6, pages 81 to 94, 1994, which is hereby incorporated by reference. The filtering performed according to the present invention allows to filter out influences caused by other projections onto the current projection, which allows to improve the quality of the data reconstruction, i.e. in case images are reconstructed, it allows for an improved image quality. Furthermore, according to the present invention, several projections / backprojections may be performed simultaneously, allowing for a high processing speed.

These and other aspects of the present invention will become apparent from and elucidated with reference to the embodiments described hereinafter.

Exemplary embodiments of the present invention will be described in the following, with reference to the following drawings:

Fig. 1 shows a schematic representation of an image processing device according to an exemplary embodiment of the present invention, adapted to execute a method according to an exemplary embodiment of the present invention.

Fig. 2 shows a thorax phantom, reconstructed with one iteration of ART with $\lambda = 1$.

Fig. 3 shows a comparison of SART (left) and a reconstruction performed in accordance with an exemplary embodiment of the present invention (right) for $M = 32$ (1 iteration, $\lambda = 1$). Where M is the number of simultaneously processed views.

Fig. 4 shows another comparison of SART (left) and a reconstruction performed in accordance with an exemplary embodiment of the present invention (right) for $M = 64$ (1 iteration, $\lambda = 1$).

Fig. 1 depicts an exemplary embodiment of an image processing device according to the present invention, for executing an exemplary embodiment of a method in accordance with the present invention. The image processing device depicted in Fig. 1 comprises a central processing unit (CPU) or image processor 1 connected to a memory 2 for storing projection data and the data generated during the iterative data reconstruction. The image processor 1 may be connected to a plurality of input/output-network - or diagnosis – devices, such as an MR device, or a CT device. The image processor 1 is furthermore connected to a display device 4 (for example, to a computer monitor) for displaying information or images computed or adapted in the image processor 1. An operator may interact with the image processor 1 via a keyboard 5 and/or other output devices which are not depicted in Fig. 1.

The image processing device depicted in Fig. 1 may be operated on the basis of the ART reconstruction technique.

The basic idea of ART used according to the present invention is to use a discrete representation I of the continuous object function and to calculate projection data from it. I is modified, if there if a difference between the calculated projection data and the measured data.

Let the measured projection data p consist of X views $p_1 \ldots, p_X$.
One iteration step $k \mapsto k+1$ consists of two operations:

1: For a given view $n(k)$ projection data p' is calculated from an estimated image I_k and is compared with the measured data $p_{n(k)}$. (projection)

$$p' = P_{n(k)} I_k$$

$P_{n(k)}$ denotes the projection operator for view $n(k)$.

2: The estimated image is updated depending on the observed difference between the measured and the calculated projection, resulting in a new estimate I_{k+1}. (backprojection)

$$I_{k+1} = I_k + \lambda_{n(k)} \cdot B_{n(k)} (p_{n(k)} - p')$$

$B_{n(k)}$ is the backprojection operator for view $n(k)$.

n is the sequence in which the projection data from different views is processed (i.e. $n : N \mapsto \{1, \ldots, X\}$). λ is a weighting factor that controls how much of the observed difference is backprojected into the new image.

A drawback of ART is that the computational effort is fairly high. This may be overcome by using a dedicated image reconstruction hardware, such as a dedicated CPU which can calculate several projections/backprojections simultaneously. As one

iteration step in ART consists of one projection/backprojection pair, ART has to be modified to use several projections simultaneously. This leads to the simultaneous algebraic reconstruction technique (SART), which may be used to operate the image processing device depicted in Fig. 1.

In SART M projections/backprojections are processed simultaneously in each iteration step $k \mapsto k+M$:

1: Projection data p'_j is calculated from an estimated image I_k and compared with the measured data $p_{n(k+j)}$ for all $j \in [0,...,M-1]$. (projection)

$$p'_j = P_{n(k+j)} I_k \quad \forall_j \in [0,...,M-1]$$

Let

$$\Delta_j = \lambda_{n(k+j)} (p_{n(k+j)} - p'_j)$$

2: The estimated image is updated depending on the observed difference between the measured and the calculated projection, resulting in a new estimate I_{k+M}. (backprojection)

$$I_{k+M} = I_k + \frac{1}{M} \cdot \sum_{j=0}^{M-1} B_{n(k+j)} \Delta_j$$

The factor $1/M$ in the backprojection step is due to the fact that projections from different angles partly contain the same information about the object. For example, all projections contain the dc value (overall average) of the object. While the factor $1/M$ is adequate for the dc component, it is too high for higher frequency components. This leads to slow convergence.

According to a preferred embodiment of the present invention, the image processing device depicted in Fig. 1 is adapted to perform the following method of operation, which is referred to in the following as filtered SART.

According to this exemplary embodiment of the present invention, a filtering step is introduced, which is performed before backprojection. Advantageously, the filtering may be adapted such that a mutual influence of the plurality of projections may be filtered out, thus allowing for an improved image quality. In other words, the slow convergence due to correlations between the simultaneously presented data may be significantly improved and thus the image quality may be improved. According to an exemplary embodiment of the present invention , the filtered SART may be described as follows:

Step 1: Projection

Projection data p'_j is calculated from an estimated image I_k and compared with the measured data $p_{n(k+j)}$ for all $j \in [0,...,M-1]$. (projection)

$$p'_j = P_{n(k+j)} I_k \qquad \forall j \in [0,...,M-1]$$

Let

$$\Delta_j = \lambda_{n(k+j)} (p_{n(k+j)} - p'_j)$$

Step 2: Filtering:

Let

$$\tilde{\Delta}_0 \approx \Delta_0$$

and

$$\tilde{\Delta}_j = \Delta_j - P_{n(k+j)} \sum_{i=0}^{j-1} B_{n(k+i)} \tilde{\Delta}_i \qquad j=1,\ldots,M\text{-}1$$

It can be shown that one step of filtered SART gives the same result as M steps in ART.

As may be taken from Step 2, the filtering is performed such that a product of a projection of a current angle and an accumulation of backprojections of preceeding angles is subtracted from the difference image $\tilde{\Delta}_j$. Advantageously, as already indicated above, this allows to filter out influences of other projections on the current projection.

The above filtering step involves operations of the type $P_i B_j$. It should be noted that this is a mapping from projection space into projection space. The combined operation can be expressed analytically and discretized in a second step. This means, the backprojection and projection operations in Step 2 do not have to be carried out as such, in contrast to Steps 1 and 3. Only the much simpler combined operation $P_i B_j$ has to be carried out instead.

Depending on the system geometry, other simplifications may apply, for example, in the case of a CT system, it is obvious that $P_i B_j$ depends only on $i - j$.

Figs. 2 to 4 show images of a FORBILD thorax phantom reconstructed with ART, SART and filtered SART according to the present invention (hounsfield units, level = 0, window = 400). All images are the result of one iteration with a constant value of $\lambda = 1$. Fig. 2 shows a thorax phantom reconstructed with one iteration of ART. Fig. 3 shows a comparison of SART (left) and filtered SART (right) for $M = 32$. Fig. 4 shows a comparison of SART (left) and filtered SART (right) for $M = 64$.

As may be taken in particular from the SART images on the left sides of Figs. 3 and 4, the image quality of the SART images is worse than the image quality of the ART image depicted in Fig. 2. This is due to the conservative up-date weighting of $1/M$. On the other hand, as may be taken from the filtered SART images on the right side of Figs.

3 and 4, the filtered SART images have substantially the same or may even have an improved quality in comparison to the ART image depicted in Fig. 2.

As indicated above, the above described image processing device and method of performing an iterative data reconstruction may, in particular, be applied in computed tomography. However, it may also be applied in nuclear imaging or X-ray imaging.

CLAIMS

1. Method of performing an iterative data reconstruction comprising the steps of:

(a) determining projection data from estimated data for a plurality of projections;

(b) determining a difference between the estimated data and measured data;

(d) performing a filtering of the difference resulting in a filtered difference; and

(e) performing a back-projection by updating the estimated data by using the filtered difference.

2. The method of claim 1,

wherein the filtering is performed such that a mutual influence of the plurality of projections is at least partly filtered out.

3. The method of claim 1,

wherein the method is based on the algebraic reconstruction technique (ART).

4. The method of claim 1,

wherein at least one of steps (a), (b), (c) and (d) is performed simultaneously for at least two projections of the plurality of projections.

5. The method of claim 1,

wherein for determining the filtered difference, a product of a projection of a current angle and an accumulation of back-projections of preceding angles is subtracted from the difference.

6. The method of claim 1, wherein the estimated data is an estimated image and wherein the difference is a difference image.

7. The method of claim 1,

wherein the method is applied in computed tomography.

8. Image processing device, comprising:

a memory for storing projection data; and

an image processor for performing an iterative data reconstruction, wherein the image processor is adapted to perform the following operation:

(a) determining projection data from estimated data for a plurality of projections;

(b) determining a difference between the estimated data and measured data;

(d) performing a filtering of the difference resulting in a filtered difference; and

(e) performing a back-projecting by updating the estimated image by using the filtered difference.

9. Computer program for an image processing device comprising a processor, wherein the computer program comprises computer program code causing the processor to perform the following operation when the computer program is executed on the processor:

performing an iterative data reconstruction comprising the steps of:

(a) determining projection data from estimated data for a plurality of projections;

(b) determining a difference between the estimated data and measured data;

(d) performing a filtering of the difference resulting in a filtered difference; and

(e) performing a back-projecting by updating the estimated image by using the filtered difference.

ABSTRACT

Iterative data reconstruction

Iterative algorithms which may be used for image reconstruction, consisting of alternating projections and backprojections usually have a slow convergence, due to correlations between simultaneously processed data and consequently a low image quality. According to the present invention, a filtering step is introduced before backprojection, allowing a parallel processing without the loss of convergence speed or image quality. Advantageously, this may allow to perform several projections/backprojections simultaneously.

(Fig. 1)

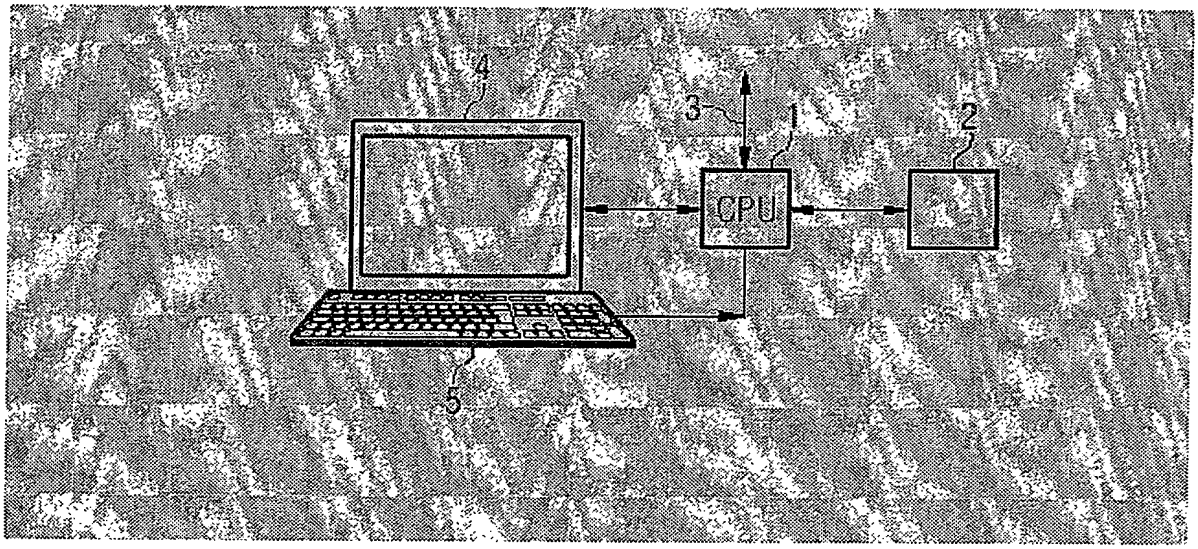

FIG 1

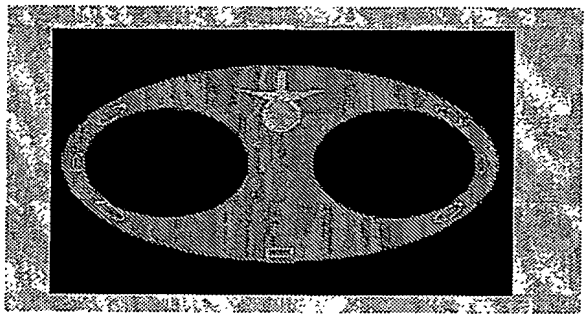

FIG 2

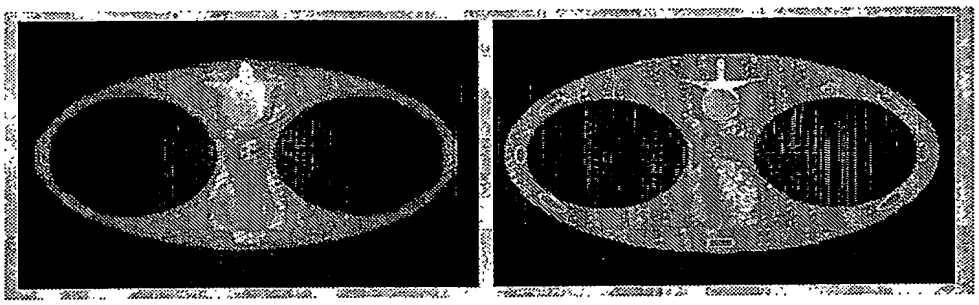

FIG 3

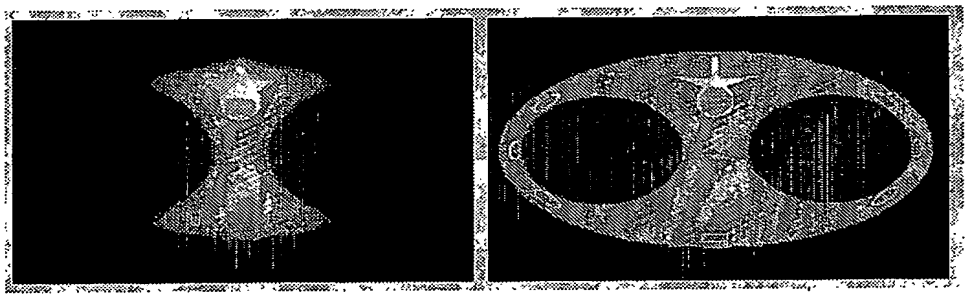

FIG 4

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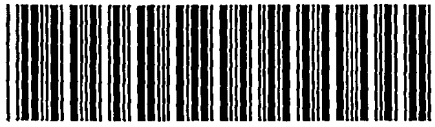

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